Canada's Nuclear Regulator

Evaluation of Facilities Handling Tritium

Part of the Tritium Studies Project

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Evaluation of Facilities Handling Tritium

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Cover images (from left to right)
A **bubbler** monitors tritium in the air.
In a **tritium recovery rig**, gaseous tritium light source tubes are crushed and the tritium is recovered.
A **filling rig** is used to insert tritium into glass tubes at a gaseous tritium light source facility.
A **bulk splitter** dispenses tritium from the commonly-used Amersham container onto smaller getter beds.

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EXECUTIVE SUMMARY

In January 2007, the Canadian Nuclear Safety Commission (CNSC) Tribunal directed CNSC staff to initiate research studies on tritium releases in Canada. In response, staff initiated a "Tritium Studies" project with several information gathering and research activities extending to 2010. The objective of this major research project is to enhance the information used in the regulatory oversight of tritium processing and tritium releases in Canada. The Evaluation of Facilities Handling Tritium *report is part of this project.*

Tritium is a radioactive form of hydrogen that occurs both naturally and as a by-product in nuclear reactors and tritium processing facilities. Tritium exposure can pose a health risk if it is ingested through drinking water or food, inhaled or absorbed through the skin.

In this report, CNSC staff compiled and evaluated facility designs and pollution prevention technologies for Canadian licensees releasing tritium to the environment, and compared these to best practices for similar facilities outside Canada. More specifically, this report:

- identifies appropriate best practice for the handling and control of tritium in Canada
- evaluates the operating performance of Canadian tritium producers, processors and major users
- compares the operating practices of the Canadian tritium processing licensees to industry best practice

The evaluation of Canadian facilities included six licensees that produce or process tritium, or manage tritium wastes:

- Darlington Tritium Removal Facility (largest tritium handling facility in Canada)
- Atomic Energy of Canada Limited Chalk River Tritium Laboratory (dispenses tritium for Ontario Power Generation tritium customers)
- SRB Technologies (gaseous tritium light source facility)
- Shield Source Inc. (tritium light source manufacturer)
- Kinectrics Inc. (engineering design company doing tritium development work)
- GE Hitachi Nuclear Energy Canada Inc. (designing a tritium removal facility)

Three facilities were also visited overseas:

- United Kingdom: GE Healthcare Ltd. (tritium separation facility)
- South Africa: NTP Radioisotopes (Pty) Ltd. (radioisotopes and gaseous tritium light source facility)
- Switzerland: Mb Microtec AG (gaseous tritium light source facility)

Study Results

The results were grouped into 13 topic areas that are each discussed in detail in the report: containment, double-walled getter beds, vacuum pumps, vacuum technology, loss due to leakage, loss due to pipeline purging, abatement, ventilation, release point design, tritium recovery, tritium storage, performance metrics, and releases to sewers.

The overall conclusion is that current Canadian practice is comparable to that in overseas facilities. Effective management of tritium is being achieved through a wide variety of mechanisms and includes many custom-designed strategies that achieve good levels of tritium control through diverse mechanisms.

In Canada, it would be possible to establish a performance metric that requires licensees to report the percentage of losses to the environment and transfers to any waste facility. This would complement existing regulatory performance metrics based on the reporting of doses to workers and the public. For new facilities, these performance metrics could be used as design parameters.

The report concludes with the following observations on best practices:

1. use of high performance vacuum equipment for gaseous tritium handling
2. focus on high quality primary containment, i.e. maintain a nearly leak-proof facility as the most important control feature through the use of reliable, high quality valves, pipes and pipe connections
3. use of uranium getter beds for operational storage of tritium gas
4. use of titanium getter beds for the long-term storage of tritium gas
5. use of direct adsorption onto getter beds, or inert gas purging and capture onto getter beds during processing operations. (Intentional release of tritium gas from pipe work and vessels is not good practice)

6. use of oil-free scroll pumps wherever possible

7. removal of tritium gas and HTO (molecule of hydrogen + tritium + oxygen) from vacuum pump exhaust, provided there is a treatment or disposal route for the abated tritium

8. reduction of chronic releases through additional secondary containment of getter beds, particularly for beds that are used at elevated temperatures over prolonged periods of time

9. focussing of abatement technology at the point of generation of the release

10. use of appropriately designed release points (stacks) for ventilation systems to achieve good dispersion of tritium gas and tritiated water vapour

1. INTRODUCTION

1.1 Tritium Studies Project

This report is one of several documents produced as part of the Canadian Nuclear Safety Commission's (CNSC) Tritium Studies Project, which was described in the CNSC Tritium Studies Charter of June 2007. This report, titled *Evaluation of Facilities Handling Tritium*, documents the work done in support of section 5.4 of the charter. Below is a description of section 5.4.

> "CNSC staff will compile and evaluate facility designs and pollution prevention technologies for licensees releasing tritium to the environment in Canada, and will compare these to best practices for similar facilities outside Canada. This evaluation will involve licensees that produce or process tritium, or manage tritium wastes.
>
> This activity will focus on:
>
> - review of existing best practice tritium processing and management information
> - the principal Canadian generators, namely Ontario Power Generation (OPG) and Atomic Energy Canada limited (AECL)
> - the principal Class 1B licensees using tritium in a manufacturing process, namely SRB Technology (SRBT) and Shield Source Inc. (SSI)
> - the larger nuclear substance licensees
> - Canadian companies with tritium engineering expertise
> - two tritium light manufacturers in Switzerland and South Africa
>
> The deliverable will be a report covering the following:
>
> - the appropriate best practice for the handling and control of tritium in Canada
> - the operating performance of Canadian tritium producers, processors and major users
> - a comparison of the operating practices of the Canadian tritium processing licensees to best industry practice"

1.2 Tritium Gas Handling "Best Practice"

In this report, the term "best practice" will be used in reference to technology that is available to reduce releases of tritium to the environment. Where "best practice" is discussed, it will be with reference to processes or technologies that reduce releases of tritium, and not necessarily to overall cost effectiveness or efficiency of a production process.

The *Nuclear Safety and Control Act Radiation Protection Regulations* call for the radiation dose to the workforce and the public to be as low as reasonably achievable. This is known as the ALARA principle. In Canada, this principle is a legal requirement, as described in section 4(a) of the *Radiation Protection Regulations*. It is this principle that will guide the discussion in this document with respect to "best practice".

1.3 Objectives and Scope

The objective of this paper is to:

- identify good practice in the control of tritium gas, with respect to keeping releases of tritium gas and tritiated water to the environment as low as reasonably achievable
- review the operating performance of Canadian tritium users with respect to releases to the environment
- make comparisons between Canadian tritium users and overseas tritium users, with respect to the control of releases
- identify changes and improvements that could be made to improve the regulation of tritium in Canada

The report is focused on the control of tritium, in order to reduce any releases to the environment from companies using tritium as part of a manufacturing process. It is neither a full review of tritium engineering practice, nor is it a review of new tritium processing where tritium is used as a fuel. CNSC staff notes that there is significant work being carried out in Europe, Japan and the USA on fusion technology. This work has already generated technical knowledge and experience currently in use, and may lead to new technologies that could be utilised by the Canadian tritium industry in the future.

1.4 Best Practice Review Methods

Tritium handling information has been reviewed from a number of sources. These include the US Department of Energy (DOE); published texts on the handling of tritium; previous CNSC published documents on tritium handling and use; conference reports and information coming out of the last international tritium science and technology conference in the United States.

The major Canadian users of tritium were identified from the list *of Nuclear Safety Control Act* (NSCA) Class 1 and nuclear substance licence holders. Canadian companies with expertise in tritium handling were also identified from nuclear engineering trade journals. Contacts were made with all the identified companies, requesting their assistance with this project. Those companies that volunteered to assist with the project were visited, their staff was interviewed, and documentation was often provided to CNSC staff.

A similar review was undertaken for companies manufacturing Gaseous Tritium Light Sources (GTLS) overseas, as well as companies handling significant quantities of tritium. Three overseas companies volunteered to assist the CNSC. Again visits were made to their facilities, staff was interviewed and some documentation was provided.

Every company that provided assistance during this project is acknowledged at the end of the report.

2. TRITIUM TECHNICAL INFORMATION

2.1 Tritium Isotope

Tritium is a radioactive form of hydrogen, with a decay half-life of 12.3 years. It emits very low energy beta radiation, which is completely absorbed by common materials, such as sheets of plastic, paper, glass or metal. In Canada, the control of tritium releases to the environment is particularly important, since CANDU reactors produce significantly more tritium than most other types of reactors – due to the use of heavy water (deuterium) in the moderator and heat transport system. Tritium is extracted from the heavy water at the Darlington Tritium Removal Facility, where it is stored. It is sold to GTLS manufacturers, both in Canada and overseas.

2.2 Tritium Gas Properties

Tritium gas (T_2) is a radioactive form of hydrogen gas, (H_2). It is chemically and physically almost identical to hydrogen gas, and for the purposes of this report it can be considered identical. It should be noted that, unlike hydrogen, the mass quantity used in most tritium handling facilities is very small. One gram of pure tritium gas at 0°C and sea-level atmospheric pressure will have a volume of 3.7 L. This, in radioactivity units is the equivalent of 3.56×10^{14} becquerels (Bq) or 356 TBq.

2.3 Chemical Compounds Containing Tritium

Pure tritium gas (T_2)is only seen inside processing equipment. As soon as it comes into contact with atmospheric air, it rapidly combines with small quantities of free hydrogen in the air and forms the more stable form of tritium gas HT. This is the type of tritium gas released into the air from tritium handling facilities.

Tritium gas will also oxidize in air – over a period of hours or days – to form tritiated water (HTO). HTO can also be produced rapidly when tritium gas comes into contact with metal surfaces in air. The metal surface will act as a catalyst in the presence of air (oxygen) and form HTO. Tritiated water is chemically and physically almost identical to ordinary water, and for the purposes of this report it can be considered to be identical. These three tritium-containing compounds are the substances of most interest in this report. The processes used to limit the releases of tritium to the environment are largely focused on the capture and removal of T_2, HT and HTO.

3 ENGINEERING AND THE CANADIAN EXPERIENCE

3.1 Hydrogen and Vacuum Engineering

Hydrogen gas is one of the most difficult gases to contain, as it is a very small light and energetic molecule. It is small enough to diffuse through metals at low but measurable rates, under high-temperature and high-pressure conditions.

It is, however, a useful – and therefore widely used – industrial gas. Consequently, the handling requirements for hydrogen gas are well understood, and once the appropriate engineering controls are applied, it is routinely and safely used all over the world. The same engineering technology that has been developed for the processing of hydrogen can be used for tritium handling and processing.

Vacuum technology is widely used in research, and very high quality vacuum equipment is readily available. For the manufacturing industry, which uses approximately a gram of tritium per day, small scale high-vacuum equipment is the preferred choice for transferring tritium gas from storage vessels to the point of use.

3.2 Darlington Tritium Removal Facility

Ontario Power Generation (OPG) operates the largest tritium handling facility in Canada, and possibly the world, at the Darlington power reactor site. The Darlington tritium removal facility (TRF) reduces the tritium content of CANDU reactor moderator and stores the pure tritium gas (T_2) on titanium metal. It is a large and complex process, producing between one and two kilograms of tritium gas per year (356-712 x 10^3 TBq per year). This tritium is stored on titanium metal inside stainless steel containers. The process during which pure tritium is produced and then transferred to the titanium storage beds is of most relevance to this study.

A review of the historical data on the amount of tritium processed and the atmosphere and liquid tritium releases from the facility indicates that the losses are in the region of 0.03%. For a complex process, handling in excess of 1,000 tonnes of moderator per year, this is considered to be very good performance.

The facility released 95 TBq of HT gas to the atmosphere in 2006. The tritium HTO concentration in air at the boundary of the facility varied from 0.3 to 3.3 Bq/m^3 at this time. The highest concentration nearby at McLaughlin Bay in Lake Ontario surface water was 24.2 Bq/L.

In discussions with OPG staff, a number of relevant issues and good practices have been suggested. These are detailed below.

3.2.1 Design

The process has a number of separate unit operations, which can be isolated or shut down individually in the event of a leak or malfunction. This can reduce the consequence of any failure causing a release to the environment.

3.2.2 Primary Containment

Primary containment is the most important part of tritium gas control. Maintaining a leak-proof facility is the main challenge, as the recovery of leaked gas will never be 100% efficient, and this means using high quality valves, pipes and pipe connections. For example, high vacuum bellows valves made of inconel (a nickel-chromium alloy very resistant to oxidation and corrosion, and therefore well suited for service in extreme environments) are widely used in the tritium gas handling part of the process. The reliability of components is important, as leaks caused by failed components can affect the quality of the product and will result in increased releases.

3.2.3 Contamination Control

Contamination control is an important operational practice to reduce tritium hazards and potential losses. This can be performed routinely, to allow easy access to components or to control releases during maintenance and repair activities. TRF staff provided two examples where contamination control is planned into maintenance and repair activities. The first was the purging of pipes and valves with inert gases, to remove the residual tritium gas. The second consisted in the vacuum heating of pipes and vessels, with the purpose of de-gassing internal pipe surfaces before equipment replacement.

3.2.4 Secondary Containment

Each week, the Tritium Removal Facility produces a few millilitres of liquefied tritium gas. The liquefied tritium gas is transferred onto a permanent storage material, in what is referred to as the tritium immobilization system, inside a separate, argon-filled glove box. This box has an internal argon gas re-circulation system, operating continuously. Its purpose is to provide a secondary containment in the event of a serious leak. By using an inert atmosphere, it is possible to recover the majority of the tritium released into the glove box, a sealed box used to control hazardous materials. The tritium is adsorbed onto uranium metal in this system, which allows for its convenient recovery at a later date.

3.2.5 Ventilation Control and Release

The TRF has its own ventilation system and release point. There is a 2-metre diameter, 10-metre high stack on the roof of the building. The building is 143 m tall, so the actual release point is 153 m high. The air being discharged is a combination of process air and building ventilation air. The flow velocity and the volumetric flow rate are 13 m/s and 60 m^3/s, respectively.

3.2.6 Tritium Storage

This facility has accumulated 20 years of experience in storing tritium on titanium metal. The current storage method is considered by OPG to be appropriate, and titanium metal is the preferred material for long-term storage of tritium gas. When tritium comes into contact with titanium, it adsorbs onto the metal and reacts to form a solid compound, called titanium tritide. In this form, tritium is no longer a volatile gas, but a stable solid. When the tritium is required in its gaseous form, it can be released by heating the titanium beds between 550°C and 700°C. When this is done, the metal is degraded and its capacity for storing tritium is significantly reduced. The titanium bed would be considered a waste material, and would not be used again.

Uranium metal is also used in the facility for temporary storage of tritium, as described in section 3.2.4 above. Uranium forms a less stable tritide, which can be released in a controlled manner by heating it to temperatures around 400°C. This procedure has the advantage that the uranium metal bed can be reused many times.

3.3 AECL Chalk River Tritium Laboratory

Atomic Energy Canada Limited (AECL) operates a tritium facility at the Chalk River Laboratory site. This facility is called the Tritium Laboratory, and its primary function is to dispense tritium for OPG tritium customers. It handles around 3.7 E^{+16} Bq per year (104 grams).

3.3.1 Description of the Tritium Processing Glove Box

This facility comprises a large glove box, split in two. The upper section is argon-filled, and works under a slight positive pressure. The lower section is a conventional air-filled box, working under a slight negative pressure. The upper box contains the tritium handling apparatus, while the lower box contains the tritium clean-up system and some additional vacuum pumps. The glove boxes are vented to the building ventilation system, which releases the exhaust air through a 25-metre high stack.

3.3.2 Primary Containment

The tritium handling apparatus was designed to be a high vacuum, multipurpose tritium gas dispensing facility. It consists of high vacuum pipes and valves, with mainly metal-to-metal compression fittings. The use of compression fittings allows for easier modifications, when required. The valves are mostly high vacuum bellows valves. The facility contains large quantities of tritium gas over prolonged periods of time. Even small leaks of gas can involve a considerable number of becquerels, so a secondary containment system is also used to protect the workforce.

3.3.3 Secondary Containment

The secondary containment comprises the glove boxes. The upper box has an argon atmosphere and a gas clean-up system, to remove tritium levels to below 1.3 E^{+10} Bq/m^3. The equipment for the gas clean up is inside the lower glove box. The lower glove box is a conventional glove box, vented to the laboratory ventilation system.

3.3.4 Glove Box Clean-up

The argon gas in the glove box is continuously recycled through a titanium getter bed, which removes oxygen, nitrogen, water vapour, hydrogen and tritium. This getter bed has to be replaced every two or three years. There is another zirconium and iron metal alloy getter bed in the lower glove box, acting as a back up for the titanium bed and available in the event of a sudden release of tritium into the upper glove box.

3.3.5 Vacuum Pumps

This facility has a number of vacuum pumps, some oil-filled and others dry. The oil-free scroll pump in the upper glove box has never required replacing and is still operating satisfactorily.

There is an oil-filled vacuum pump in the lower glove box. The oil inside oil-filled pumps is changed yearly and transferred, as low level waste, to the waste management facilities on site. The tritium concentration in the oil is around 3.0 E^{+10} Bq/L.

3.3.6 Tritium Storage

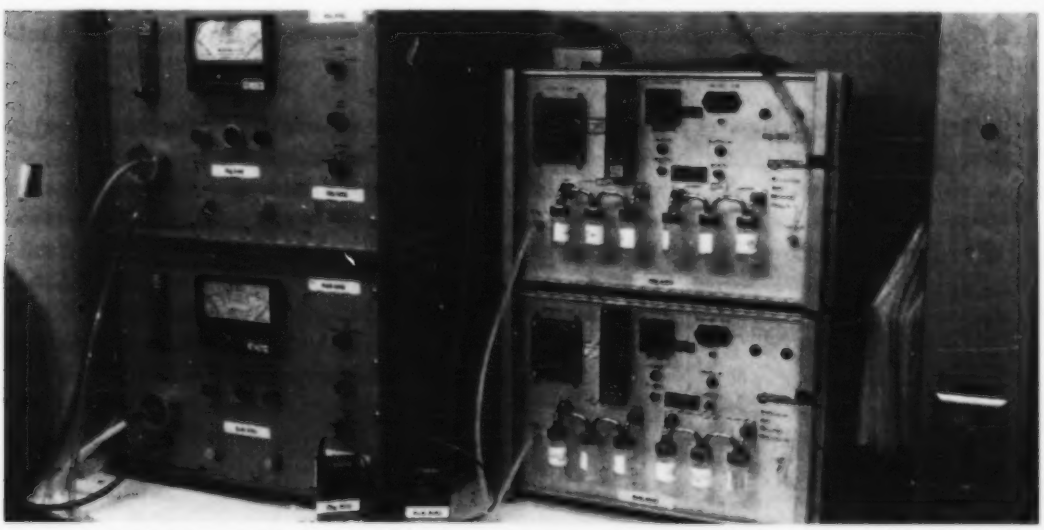
Once the tritium has been removed from the titanium beds, it is held on one of two uranium beds in the glove box. Tritium is held on these beds until there is a requirement to dispense tritium for a customer.

It was suggested that these two beds are probably the biggest source of continuous release of tritium into the glove box. This is because they are single-walled, and both have gone through many heating cycles.

3.3.7 Releases to Environment

The release of tritium through the stack is continuously measured using bubblers and a platinum catalyst oxidizer. The sampling system allows for the measurement of HTO and HT releases. The monitoring results indicate ratios of around 20 to 40% of HTO, and 60 to 80% of HT in the aerial releases.

The total amount of tritium released from the facility in a year is around 3.7 E^{+12} Bq. This represents about 0.01% of the material being handled. The concentration of tritium in the stack varies from 0 to 1.8 E^{+5} Bq/m^3 when the laboratory is not processing tritium, to 1.8 E+6 Bq/m^3 when tritium is being dispensed.

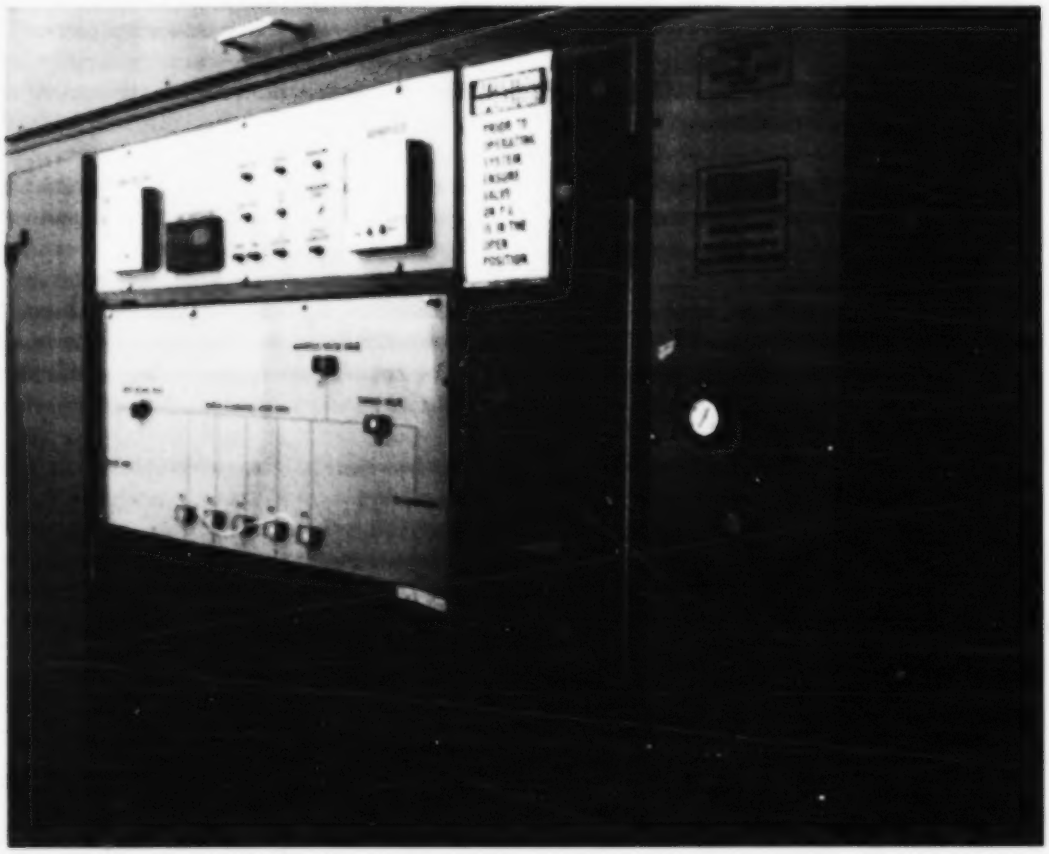


Releases of tritium through the stack are continuously sampled using bubblers. When air containing tritiated water vapour is bubbled through normal water, the tritiated water collects in the bubbler. Often, two or three bubblers are connected in series, to ensure good sample collection.

3.4 SRB Technology

SRB Technology (SRBT) has operated a gaseous tritium light source (GTLS) facility in Pembroke, Ontario, since 1991. They manufacture self luminous signs, dials and instruments. The tritium handling part of this facility comprises a receipt and dispensing apparatus, several tube filling rigs and a tritium recovery rig.

The facility has evolved over time, and in recent years has been under regulatory scrutiny, because its releases were considered by the CNSC to be impacting the environment. As described later in this report, this facility provides an example of how basic engineering improvements and changes to operating processes can reduce releases to the environment.



A typical filling rig is used to fill glass tubes with tritium gas at a gaseous tritium light source facility.

3.4.1 Description of the Tritium Handling Equipment

Tritium is delivered in a certified uranium bed transport container, known as an Amersham AY 0666. The tritium is removed from this container and split (or dispensed) onto a variety of smaller uranium beds. This is done in a dedicated vacuum apparatus, built inside a fume hood.

There are several filling rigs for different types of tubes, each one being a separate apparatus. They are either built into a fume hood or are connected to the fume hood ventilation system.

A tritium recycle rig was used for crushing old tritium light source tubes and extracting the tritium for reuse. It consisted of a vacuum system, containing a mechanical crusher built into a fume hood. This equipment was not very efficient and, having contributed to high releases of tritium to the environment in the past, is no longer in operation.

3.4.2 Design and Evolution

The tritium handling equipment has evolved to meet customer requirements. It is built using high vacuum technology and equipment. The facility is well ventilated, with a cascaded ventilation system designed to quickly remove any tritium released during the process operations. The multiple rigs provide a considerable degree of flexibility and are relatively easy to modify largely because they are built using vacuum technology and compression fittings.

The vacuum pumps were originally oil-filled pumps, but these were replaced over time by dry-scroll type vacuum pumps. The exhaust from the vacuum pumps is vented to the building ventilation system.

In recent years, much of the apparatus has been reconfigured to reduce the diameter of pipe work and length, as a way to minimize dead space and tritium losses. The flushing of pipe work with inert gas has also been introduced, to reduce the amount of HTO released to the atmosphere.

3.4.3 Containment

The tritium handling equipment relies on primary containment to control the release of tritium. Commercially available vacuum pumps, valves and pipe fittings are used throughout the facility to provide the primary containment. The recently re-engineered rigs were rebuilt to reduce dead spaces, using high quality commercially available vacuum pipes, valves and fittings.

There is no secondary containment used in this facility. Fume hood technology is, however, used extensively and is relied upon to protect the workforce from chronic exposure to tritium gas and HTO vapour.

3.4.4 Ventilation and Releases to the Environment

The SRBT facility has a large industrial ventilation system, made up of two separate fans, motors and stacks, with integrated controls. This system provides the incoming air and directs the outgoing waste air to the exhaust stacks. Each stack is approximately 11 m high and has a terminal air velocity greater than 12 m per second.

The releases from the two stacks have been historically high; as previously mentioned, following regulatory enforcement action, the releases from the facility have been reduced. Information for recent years indicates the percentage of tritium releases, compared to the quantity of tritium used in the production process, has improved from 3.9% in 2005, to 1.3% in 2006, to 0.04% for 8 weeks in early 2007, and finally to 0.14% for the last half of 2008 when processing of tritium resumed. Recent 2008 data ranged from 0.03 to 0.08% for five months, and 0.86% for one month. The high value resulted from a single process upset that has since been corrected through the addition of secondary containment. SRBT is authorized to possess up to 6,000 TBq of tritium in any form at any time (169 grams), but typically maintains only about half this amount on the premises.

SRBT staff believes the concentration of HTO in the stack releases was reduced when oil-filled vane pumps were replaced by oil-free scroll pumps, as reflected in the sharp drop in percent releases late in 2007. However, this change occurred at the same time as other process changes were being introduced, and shortly before a prolonged shut down. It is therefore difficult to confirm the contribution of pump replacement to the recent overall decrease in tritium releases to the environment.

SRBT's sampling system measures releases of both HTO and HT. Tritium HTO releases in 2006 were 72 TBq to the atmosphere and about 0.04 TBq to the sewer. Tritium HT release to the atmosphere was 210 TBq. Tritium concentrations in air, surface water and other media such as garden produce are also routinely monitored. The HTO in air concentration at a distance of 220 m from the building varied from 3.9 to 56 Bq/m^3 at this time, and surface water in a stream near SRBT was about 5 Bq/L.

3.5 Shield Source Incorporated

Shield Source Incorporated (SSI) is a gaseous tritium light source manufacturer in Peterborough, Ontario, with a relatively small facility that has been in operation for 18 years. SSI mainly produces exit signs using straight glass tubes. They have two tritium handling rigs that combine the processes of receipt of tritium and the filling of tubes. There is no recycle rig for extracting tritium gas from expired or redundant light sources at this facility.

3.5.1 Description of Tritium Handling Equipment

There are two identical tritium receipt and tube filling rigs in a ventilated room. These rigs receive tritium in Amersham transport containers, and transfer the tritium onto uranium beds on the filling rig. The evacuated tubes are filled with tritium and sealed. Each rig fills around 1,500 tubes per day.

3.5.2 Design

The two rigs were designed to fill straight glass tubes, used in manufacturing exit signs. The rigs are compact, independent units, and are operated separately. The pipe work mostly consists of welded stainless steel, except for a small number of metal compression fittings. This is the main reason why there is limited scope for filling complex shaped tubes, or making quick changes to the process equipment layout.

The vacuum was maintained by conventional oil-filled vane pumps, exhausted directly to the ventilation system until 2008, when these pumps were replaced with oil-free scroll pumps.

A tritium recovery system is designed into the filling head that evacuates the end stub of the filling tube and draws the tritium gas back into a uranium bed. The tritium is recovered periodically and reused.

The rigs are enclosed in a fume hood type enclosure, ventilated to the facility fan and stack.

3.5.3 Containment

The tritium handling equipment relies on primary containment to control the release of tritium. Commercially available oil-filled vacuum pumps and valves are used throughout the facility, to provide the primary containment. As previously mentioned, SSI has mainly welded pipe work, and many of the valve bodies are welded directly to the pipe work. There is no secondary containment used in this facility. The rigs are built into fume hood type enclosures, to protect the workforce in the event of a tritium release.

3.5.4 Ventilation and Releases to the Environment

The facility is ventilated using a conventional industrial ventilation system, which consists of a single fan discharging to a 9-metre high stack. Based on the analysis of discharge data, the loss of tritium to the ventilation system has been consistently around 0.4% of the production throughput. Staff at the facility indicates that the introduction of oil-free scroll pumps appears to reduce the concentration of HTO in the releases.

SSI's sampling system measures releases of both HTO and HT. Tritium HTO releases in 2006 were 13 TBq to the atmosphere and about 0.02 TBq to the sewer. Tritium HT release to the atmosphere was 98 TBq. Tritium concentrations in air, surface water and other media such as garden produce are also routinely monitored. The HTO in air concentration at a distance of 210 m from the building varied from 0.3 to 3.8 Bq/m^3 at this time. The highest surface water concentration nearby was in a pond 220 m from SSI at 1,490 Bq/L.

3.6 Kinectrics Incorporated

Kinectrics is an engineering design company based in Toronto, Ontario. It has a tritium laboratory licensed by the CNSC for doing tritium development work. Kinectrics staff has been involved in the design and modification of the Darlington Tritium Removal Facility, and they have also been consultants on many tritium projects around the world. They do not manufacture any tritium containing products.

Kinectrics released 0.76 TBq of HTO and 0.17 TBq of HT to atmosphere, and 0.066 TBq to sewer in 2006. Limited measurements in environmental media near the facility are mostly below limits of detection.

3.6.1 Tritium Handling Experience

In discussion with Kinectrics engineering staff, the following comments on the design and manufacture of tritium gas handling facilities were made:

- It is better to use welded connections on all pipe work on tritium processing equipment and, if possible, it is better to use automated welding systems – for consistency.

- Metal compression seals are good for experimental facilities on valves and other parts, where changes may have to be made. However, they must be done carefully, to avoid the build up of stresses in the pipe work. Stresses in construction can cause leaks over time, especially in non-welded systems.

- Bellows valves are recommended for tritium systems, as the bellows effectively provide secondary containment.

- Overall, there is no clear advantage for the choice in vacuum systems between oil pumps and dry pumps. Oil-filled vacuum pumps are recommended, provided there is a disposal route for the waste oil. Dry pumps often need a primary and a secondary pump to get the same performance. Dry pumps are generally not as reliable as oil-lubricated pumps, but their reliability is improving. User requirements and waste handling constraints will be the key determining factors.

- The collection of HTO on dryers is easy and effective. However, if the tritium concentration is high, the handling of the desorbed water can present a serious health and safety issue. The water must be either disposed of, or put through a tritium recycle facility, like the Darlington TRF. Neither of these two options is readily available in Canada at the present time.

- In inert gas glove boxes, the zirconium iron alloy getters are effective for the removal of tritium gas, provided that the gas is free from water and oxygen.

- Having good process control metrics is the best practice for minimizing losses during tritium processing. Keeping tritium in the elemental form has been the preferred control mechanism at Kinectrics, since the substance is then easier to contain and trap. The best loss recovery technology is to recover the tritium as close as possible to the point of loss. This can be done using getter bed traps, or by oxidizing the tritium to HTO and removing it in conventional water traps. It is important to note that water has a high equilibrium vapour pressure, so the control of tritiated water is important from a health and safety perspective.

3.7 GE Hitachi Nuclear Energy Canada Inc

GE Hitachi has a design for a Tritium Removal Facility for removing tritium from a heavy water moderator. GE Hitachi agreed to discuss the design process for a tritium handling plant, based on their experience in the UK.

3.7.1 Tritium Plant Design Principles

The GE Hitachi tritium removal plant design is based on the technology and the design process used at GE Healthcare in the UK. The following design principles were identified to be relevant for any tritium handling facility in Canada:

- The whole design process from start to end product should be documented. A process flow sheet should be produced, then tested during commissioning. The current design flow sheet indicates a tritium retention rate of 99.7% in the process.

- The technology to recover tritium gas and HTO vapour loss is available. Adsorption of tritium gas on metal getters is well understood, and a variety of materials are available for different applications. The oxidation of tritium gas and the adsorption of the resulting water vapour onto molecular sieves are also well understood, and can be integrated into the process at the design stage. Water vapour condensation is a simple and useful technique for removing HTO vapour losses.

- For tritium processing plants, the best practice is to design and construct to appropriate modern standards. This, in GE Hitachi's view, results in high performance primary containment. Secondary containment is only applicable for areas where there is potential risk of a significant release, and is used mainly to protect the workforce. Inert gas and air-filled secondary containment can both be appropriate, depending on the level of risk.

- Tritium that leaks from any part of the system should be removed as soon as possible and as close as possible to the leak source. This means that the abatement technology can be optimized for the specific conditions where the release occurs. Having a cascaded ventilation system integrated with the process design and any abatement technology is recommended.

- Finally, keeping the tritium inventory as low as possible is an important design principle. This has a direct effect on any accident assessment and risk analysis.

4 OVERSEAS TRITIUM HANDLING EXPERIENCE

4.1 GE Healthcare Ltd.

Arrangements were made with GE Healthcare Maynard Centre in the UK, to visit their new Tritium Separation Facility (TSF). The Maynard centre has used tritium to label analytical and medical compounds for several decades. They have a considerable experience in the processing and the handling of tritium. The recently built and commissioned TSF is possibly the newest tritium processing facility in the world. The visit covered both the current tritium handling arrangements and the operation of the new TSF.

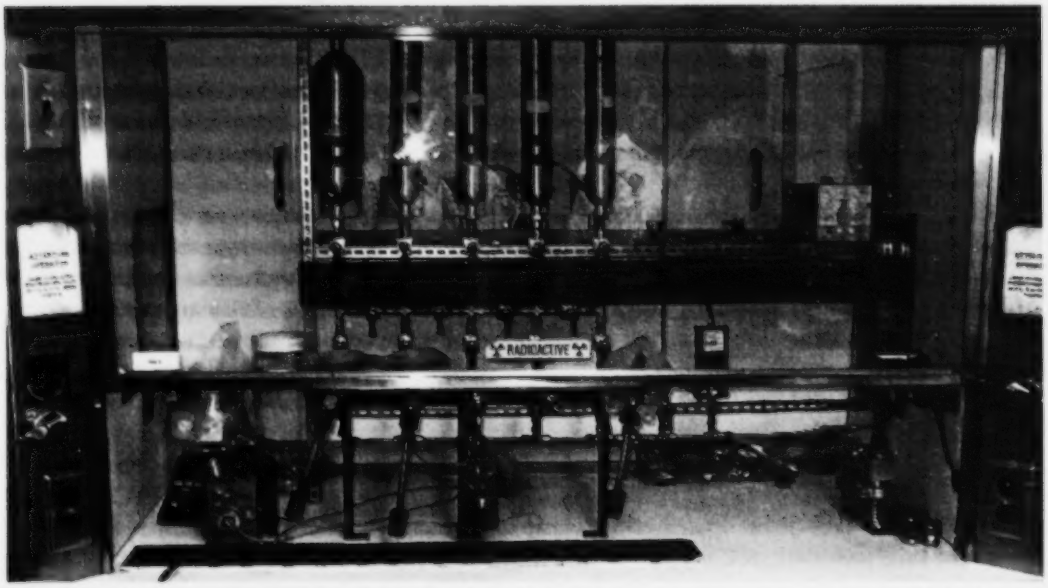
One of the more interesting process issues that this tritium labelling facility has to deal with is that about 95% of all the tritium they handle ends up in a waste product. This is either tritiated water or solvents containing a variety of complex chemicals. These are stored at the GE Healthcare site and are the reason for developing the tritium separation facility. See section 4.2.

4.1.1 Description of Tritium Handling Equipment

Tritium is received on the commonly used Amersham container, normally supplied by AECL from Canada. The tritium gas is transferred onto other smaller uranium beds for use throughout the facility. Tritium can then be used to label organic compounds, as a gas, or adsorbed onto organic solvents used as a carrier. The facility is a series of separate laboratories, each containing a large number of fume hoods. There are no glove boxes in this facility.

The rigs used for splitting tritium gas onto smaller uranium beds are built inside conventional laboratory fume hoods. They use standard vacuum equipment pipe valves, and gauges connected by metal compression fittings. The vacuum is maintained using oil-filled vane pumps and turbo molecular pumps.

The equipment for labelling compounds is of similar construction, but contains more welded pipe connections. On these labelling rigs, any residual gas left in the vessels is released to the ventilation system. There is no tritium recovery on the ventilation system.



A bulk splitter dispenses tritium from the commonly used Amersham container onto smaller getter beds, for use throughout the facility.

4.1.2 Design

The tritium rigs and equipment have evolved over 20 years of work experience. Most of the evolution was focused on reducing the tritium dose to the workforce. There is a planned in-house project to redesign and rebuild these rigs, in order to reduce wastes and releases to the environment.

It should be noted that the laboratory itself is a purpose-designed radiochemical laboratory, with a controlled cascaded ventilation system.

4.1.3 Containment

Primary containment is maintained using vacuum equipment and is leak-tested in use, through the monitoring of the vacuum quality. Any loss of vacuum is corrected before tritium is introduced. There is no secondary containment on these tritium rigs.

4.1.4 Ventilation

All releases of tritium from the laboratory rigs are directed – without recovery – into the laboratory ventilation system. This is a large system, discharging through two stacks, each 50 m high and 1.7 m in diameter.

4.1.5 Releases to the Environment

In 2007, the facility released around 300 TBq of tritium up the stack. As the facility uses around 600 TBq of tritium per year, this represents around half of the total tritium processed. It is estimated that about 5% of the tritium enters the product, so a similar quantity of tritium ends up as the liquid waste. The liquid wastes that contain most of this tritium are now stored, pending the commissioning of the new Tritium Separation Facility. This tritium will then be recovered for reuse.

Environmental samples have been measured on and around the site. The Method Detection Limit (MDL) in the dedicated environmental sample laboratory is 7 Bq/L. The following analysis results have been reported:

- foul sewer - typically 17 Bq/L
- sea water - MDL to 7Bq/L
- surface water - MDL to 10 Bq/L
- rain water - less than the MDL
- groundwater on the site has been measured at between 50 to 100 Bq/L

4.2 GE Healthcare Ltd. Tritium Separation Facility

In the time between the research and publication of this report, GE Healthcare made the decision not to operate its tritium separation facility in the UK. However, the information in this section is still relevant to the report.

This facility has been built to remove the tritium from stored liquid wastes and recover it for reuse. It is currently being commissioned.

The TSF is a complete processing facility, taking liquid tritiated waste, and where necessary, oxidizing it to produce HTO vapour. This is then processed to remove the tritium and produce a 99% pure tritium gas that is stored on uranium beds for reuse. The waste products are carbon dioxide and water with low tritium content. There are a number of abatement processes that produce a tritiated water product, which can then be returned to the beginning of the process, for recycling.

The facility is designed to process 1,258 TBq per year.

4.2.1 Description of tritium handling equipment

Each operation unit is housed in a separate fume hood or glove box enclosure. This allows them to be individually shut down if necessary. Each unit operation also has a tritium release recovery system specific to the process, which can be one or a combination of the following: gas adsorption, oxidation and water vapour removal, drying or release to atmosphere. The tritium gas handling part of the facility is contained in a fume hood. This is where measured volumes of tritium gas are adsorbed onto the uranium beds. Here the pipe work is all welded, and the valves are vacuum bellows valves. All the vacuum pumps used in the facility are oil-free. The tritium storage beds are small ones, which can be used directly in the process laboratory without any additional dispensing.

4.2.2 Design

The design flow sheet indicated an input of 1,258 TBq per year. This input will produce 1,252 TBq of tritium gas absorbed on uranium storage beds. The process loss of tritium will be approximately 0.4%.

High performance primary containment is used throughout the facility. There are sealed box type secondary containment systems on some unit operations. Most unit operations are built into a "slipbox". A slipbox is a fume hood type enclosure that has a more limited access and may have fitted ambidextrous gloves.

The tritium storage beds are deliberately small, so that they can be used directly in the process laboratory without any additional dispensing.

4.2.3 Ventilation

The ventilation for each unit operation is provided by the laboratory's ventilation system. However, most of the unit operations have their own tritium abatement system on the outlet air. This allows for small, optimized air clean-up systems to be used in the event of a leak or release from each unit operation.

4.2.4 Releases to the Environment

The design flow sheet indicates a loss of tritium to air of 0.4% of the throughput.

4.3 NTP Radioisotopes (Pty) Ltd.

NTP Radioisotopes (Pty) Ltd. is a subsidiary of the Nuclear Energy Corporation of South Africa (NECSA). The NTP Company occupies part of the NECSA site at Pelindaba, near Pretoria in South Africa. It operates a GTLS business which only represents a small part (about 1%) of NTP's overall radioisotope business. The main object of activity is producing radioisotopes for medical use and other users.

In the past, NTP bought tritium from Amersham UK (and possibly other sources.) They have not purchased tritium from any supplier for several years. Their sole source of tritium is now from recovered, out of date, or redundant GTLS.

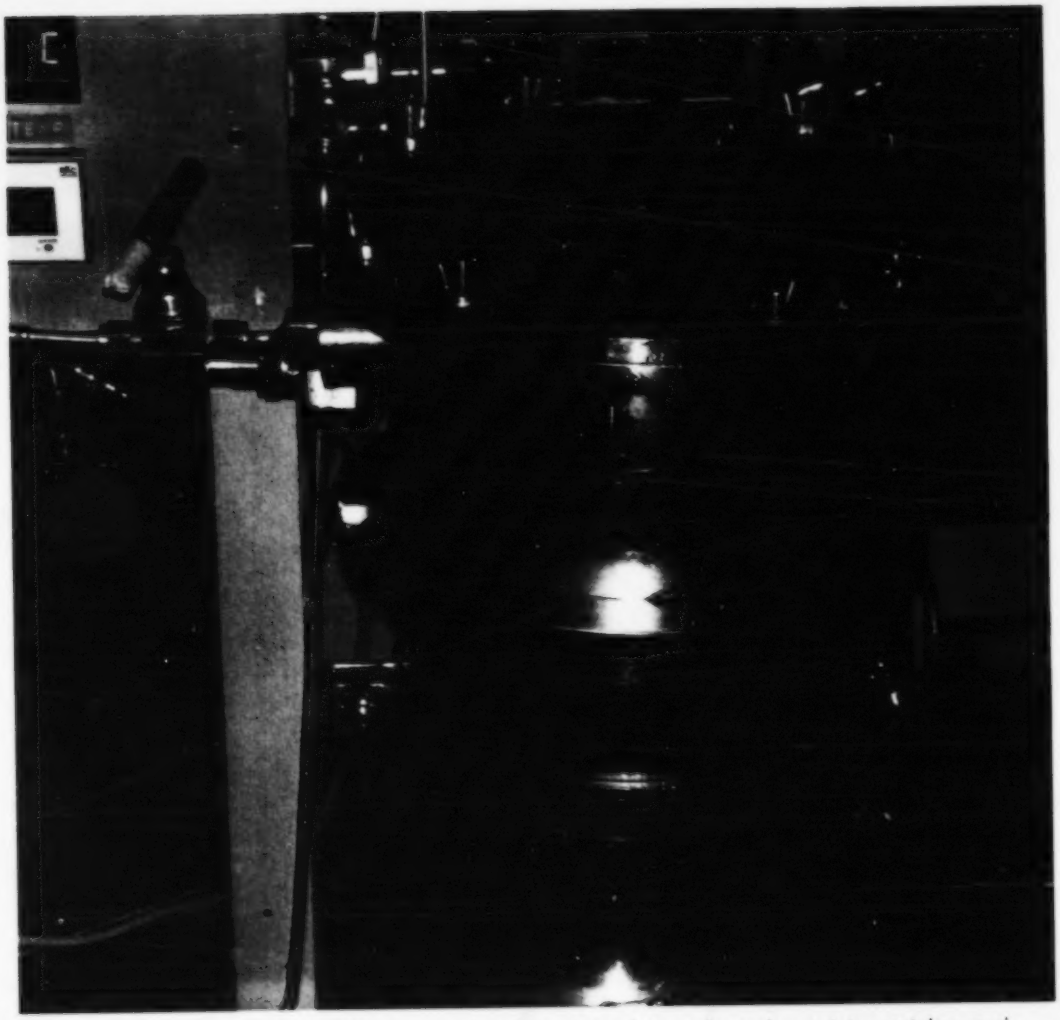
The company has recycled tritium from airport runway lights on one occasion, but their main source is GTLS from exit type signs. They only take tubes that have been dismantled, and they are very selective about what materials they will accept. This is not a waste handling process, but a recycle and reuse process.

4.3.1 Description of Tritium Recovery Equipment

Glass GTLS tubes are placed into a stainless steel vessel about 800 mm long and 300 mm in diameter. This vessel is basically a rotary mill, containing stainless steel rods. The vessel is filled with GTLS tubes and evacuated using an Alcatel vacuum pump (oil-filled vane pump) and then filled with helium gas. The filled vessel is disconnected from the evacuation rig and is moved to a rotating machine and rotated for about one hour. The glass tubes are crushed and the glass becomes a fine powder.

This vessel is returned to the vacuum system and connected to the recovery unit, where it is flushed with helium gas, through a pyrophoric uranium bed. The tritium is absorbed on the bed, and the helium is discharged to the site ventilation system.

The amount of recovered tritium varies considerably, depending on the content of the tubes. They have done some work in the past to measure the recovery rate from this process. This can be difficult, as it relies on the customer providing an accurate tritium content of the tubes. Where measurements have been done, the recovery rates varied from 95% to 98%.



In a tritium recovery rig, glass GTLS tubes are placed into a stainless steel vessel containing stainless steel rods. This vessel acts as a rotary mill. The glass tubes are crushed and the tritium is recovered. The amount of recovered tritium varies considerably; where measurements have been done, the recovery rates ranged from 95% to 98%.

4.3.2 Design

The tube filling rig is constructed of quarter-inch stainless tube, with metal sealed compression fittings connecting bellows valves and other gauges. Overall, the filling rig is based on conventional vacuum engineering. The filling heads on the rig have double o-ring seals. Rather differently from other tritium users, the getter bed used immediately before the tube-filling rig is of palladium metal. The use of the palladium bed reduces the time and the temperature that the bed has to be heated. This reduces any diffusion losses through the stainless steel body of the getter bed.

When asked about possible changes to the rig, if it were to be rebuilt now, the operators of the facility volunteered four possible improvements:

- Use ⅜ inch tube on the rig, to increase gas flow rates.
- Simplify the tritium recovery unit; it could be simpler and smaller.
- Make the crushing vessel bigger, to accommodate more tubes.
- Automate the valves on the filling rig.

4.3.3 Containment

NTP has designed the process to minimise the loss of tritium caused by diffusion into the stainless steel body of the getter beds. The uranium beds and the palladium bed comprise a stainless steel primary containment with an external electric heater. This is then put into a secondary stainless steel container. The space between the inner and outer container is evacuated, and then filled with argon gas.

An additional benefit of this inert atmosphere surrounding the heater is an extremely low oxidation rate. Only two heaters had to be replaced during the 20 years of operation at the facility.

Other than the double-walled getter beds, there is no secondary containment at the facility. The filling rig is built in to a conventional nuclear laboratory type fume hood.

4.3.4 Ventilation

The vacuum pumps and the fume hoods are ventilated into the laboratory ventilation system. This is then connected to the main site stack that is also the main ventilation stack for the "SAFARI" nuclear reactor. This is a large concrete stack 70 m tall and 2.2 m in diameter, with a flow velocity of 7.8 m/s.

4.3.5 Releases to the Environment

Measurements of tritium in air are taken near the stack, 4 m above ground. There is a small river flowing through the site, which is sampled upstream and downstream of the Pelindaba site. Samples are bulked and measured monthly for air, and every three months for river samples. Analysis is done using liquid scintillation counting. The limit of detection varied between 20 and 30 Bq/L. Sample results are usually below the limit of detection.

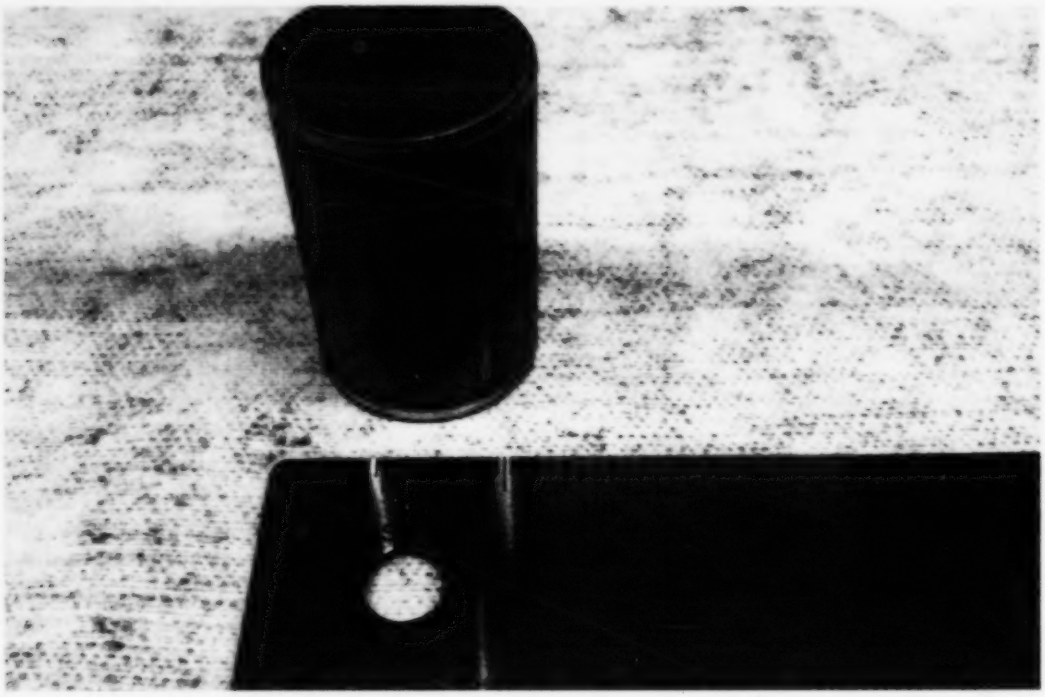
4.4 Mb-Microtec AG

Mb-Microtec is a GTLS company based in Niederwangen, near Bern, Switzerland.
It specializes in making very fine tritium light sources for watches and instrumentation.
The company's headquarters are in a light industrial area, surrounded by residential property.
They have been on this site for about 20 years.

4.4.1 Description of the Tritium Handling Equipment

Most of the tritium used by Mb-Microtec comes from AECL in Canada, and arrives in the standard Amersham container. The tritium is then dispensed into small uranium beds, used in various production processes. These beds are made in-house by Mb-Microtec. The Amersham container is connected to the splitting rig and heated to release the tritium, using an electric clamp type heater.

The splitting rig can accommodate 12 Mb-Microtec uranium beds. It is made of a ⅜ inch stainless steel tube, connected by compression fittings. Bellows valves are used on the rig, with membrane valves used on the uranium beds. Membrane valves are preferred, as they provide a better seal than metal bellows valves in the event of any uranium powder escaping from the Mb-Microtec beds and contaminating the seal surfaces. The rig is contained in a fume hood, vented to atmosphere through the building's ventilation system.



This is a example of a typical tritium bed. It contains the tritrium that is used in the production of GTLS.

The rig is evacuated using oil-free scroll pumps. The exhaust from the pump then goes to a tritium removal process, in an adjacent but separate fume hood. This process comprises a copper oxide oxidation stage, followed by adsorption onto a molecular sieve. These sieves are modular in construction, and are disposed of at a Swiss disposal facility. No attempt is made to recover the tritium.

All the vacuum pumps used in this facility are oil-free scroll type pumps. The exhaust from all pumps is directed to the oxidation and molecular sieve unit described above. The tube-filling rig is made of stainless steel pipe, connected by compression fittings. The valves are, again, metal bellows valves.

4.4.2 Design

The tritium handling rigs are built using conventional vacuum equipment. Most pipe work is connected with compression fittings, and each rig is built into a separate fume hood, connected to the building ventilation system. Redirecting the exhaust from the vacuum pumps to a tritium oxidation system and a molecular sieve was a later design change. This provided a measurable reduction of tritium release to the atmosphere, when it was introduced.

4.4.3 Containment

The primary containment is based on good quality vacuum technology. There is no secondary containment on the equipment or rigs.

4.4.4 Ventilation

The laboratory ventilation system provides five air changes per hour. The ventilation system exhausts via two roof-mounted vertical stacks. One is approximately 2.5 m high, and the other approximately 5 m high. There is no abatement system on the ventilation system, other than the vacuum pump exhaust system described previously.

4.4.5 Releases to the environment

The tritium losses to the atmosphere are around 0.4% of the tritium throughput. This represents around 30 TBq per year. The losses to sewer are 0.0001% of throughput. There are routine measurements of air, surface water and rain around the facility. The tritium in air concentration at a distance of 200 m from the building varies from 2 to 14 Bq/m^3. The maximum surface water tritium concentration is around 30 Bq/L. Tritium in rainwater at 300 m southeast varies between 20 and 400 Bq/L, and at 320 m northeast, it varies between 80 and 1,000 Bq/L.

5 DISCUSSION OF FINDINGS OF BEST PRACTICE

This section reviews the information from the various sources and identifies common issues. All facilities had some process or experience that is of value in identifying best practice.

5.1 Containment

All the companies reviewed in this document use high quality primary containment. High quality vacuum equipment is commercially available and has been successfully used for many years.

Secondary containment is not widely used in tritium gas processing. This may be because when a leak occurs during a production process it can be spotted immediately. In the GTLS manufacturing process, loss of vacuum is cited as the first indication of a leak. This would be quickly followed by an alarm from a tritium gas monitor within the ventilation system. Facilities of this type can be shut down quickly, repaired and returned to service with minimal risk to the operator.

Secondary containment is used where very large quantities of tritium gas are being handled. In Canada, two examples are the filling rig at the Tritium Removal Facility at Darlington and the tritium dispensing laboratory at AECL Chalk River. These two facilities transfer petabecquerel ($1.0\ E^{+15}$) quantities of tritium at a time. Both these facilities have inert gas-filled glove boxes, with built-in tritium recovery system. The advantage of having an inert gas-filled glove box is that the tritium can then be recovered by passing the glove box air through a getter bed.

A number of engineers suggested that secondary containment should only be used for those operations where there is a real need or quantifiable risk.

5.2 Double-walled getter beds

NTP Radioisotopes were the only example of a company routinely using double-walled getter beds. This is a good example of targeted secondary containment and targeted abatement system.

Tritium gas, like hydrogen gas, will diffuse through stainless steel at elevated temperatures. The body of a uranium bed is typically made of stainless steel. These beds are heated to temperatures above 400°C many times over a number of years. It is generally considered, in the tritium industry, that there is a chronic release of tritium from these beds, by diffusion.

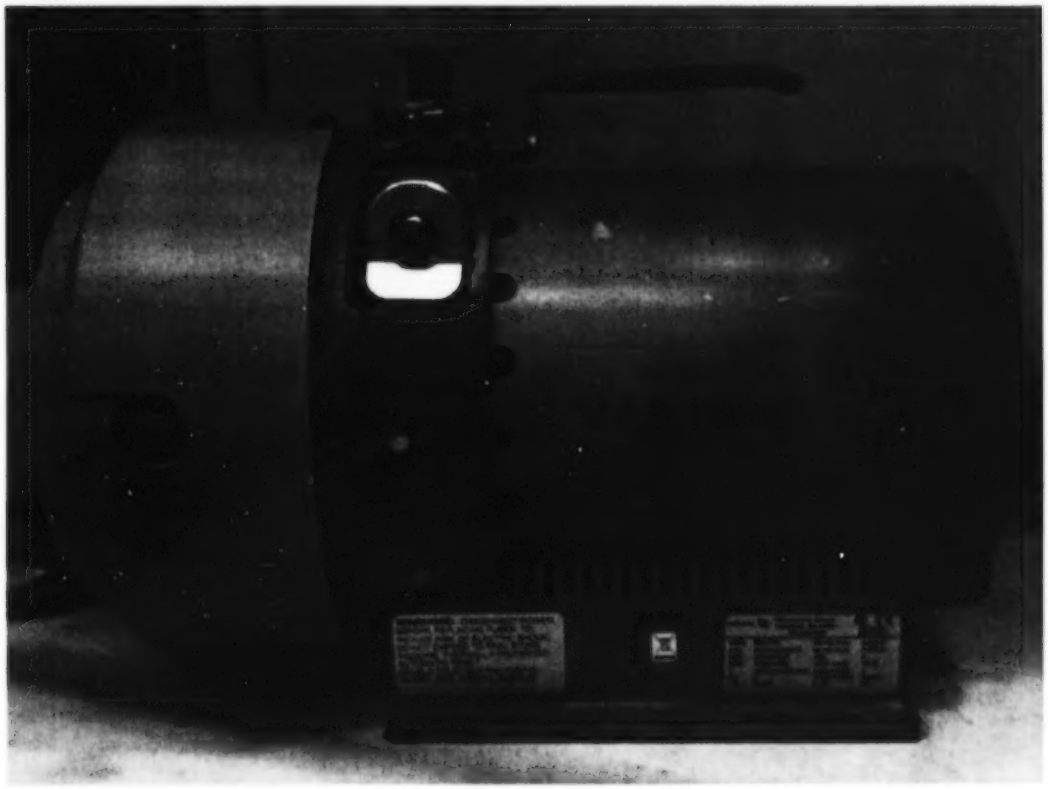
A double-walled getter bed is a form of secondary containment. Any tritium that diffuses through the primary containment will remain in the space between the two containers which can be filled with an inert gas.

The NTP getter bed is heated using a clamp type electric heater. This bed, with the heater attached, is placed inside the outer stainless steel container and sealed. The space between the two containers is evacuated and filled with argon gas. Any tritium that diffuses through the primary containment will remain in the space between the two containers, and can be periodically removed and collected on another tritium bed. An additional advantage of this system is that there is no oxidation of the electric clamp heaters. There have been only two heater failures in 20 years.

A disadvantage of this system is that a tritium bed that is normally the size of a teacup becomes as large as a gallon paint can. This makes it more difficult to refit into existing tritium processing equipment. However, it could be accommodated at the design stage of a new facility.

5.3 Vacuum Pumps

There are many types of laboratory vacuum pumps that are commercially available. Examples of most of them are in use on tritium facilities reviewed in this report. Oil-filled vane pumps are still the most flexible, and probably reliable for most applications. However, they do produce contaminated waste oil. If a disposal route for this oil is available, then they provide a reliable vacuum source. They also produce an exhaust that contains a trace amount of oil. All vacuum pump exhausts appear to be a measurable source of tritium released to the environment. For this reason, a number of companies have looked at using abatement systems for pump exhausts. In this case, oil-free scroll pumps are preferred, as their exhaust is free of trace quantities of oil – which may hamper the chosen tritium removal process. Some new evidence is beginning to appear that the exhaust from oil-free pumps has a much lower concentration of HTO. If this is confirmed, it would support the wider use of this type of vacuum pump.



Scroll pumps create a vaccuum in the filling rig. Oil-free scroll pumps are preferred, as their exhaust is free of trace quantities of oil, which may hamper the chosen tritium removal process.

5.4 Vacuum Technology

All facilities handling tritium gas are using commercially available vacuum and high-vacuum technology. There are several companies in the world producing this type of vacuum equipment. At no time was there any indication that one manufacturer was significantly better than another. One of the main differences between the various facilities is the use of compression fittings or welded connections to join vacuum pipe work. The engineering opinions obtained during this review were that welded pipe work is preferable, because it is stronger and less likely to leak. However, the pipe work assembled with compression-type joints is widely used and consistently provides adequate seals. It is also easier to modify than a welded system. In general, tritium rigs built from vacuum equipment and assembled using manufacturers' instructions or appropriate Canadian Standards Association (CSA) codes will provide high quality primary containment.

5.5 Loss Due to Leakage

Hydrogen gas is difficult to contain because it is is comprised of small energetic molecules. However, good quality vacuum engineering and equipment is adequate for the task. Hydrogen does, however, diffuse through metals – like stainless steel – at elevated temperature and pressure. There are, therefore, two areas of interest for leak management. The first is the acute loss of primary containment caused by wear, fatigue, or failure. This can occur on any part of the tritium handling system. The second is the chronic release that is believed to occur from those components that contain tritium gas at elevated temperature and pressure.

A number of companies reported that the first indication of a leak in the vacuum processing equipment was the loss of vacuum. This was usually followed, some seconds later, by elevated tritium levels registering on the tritium monitors in the ventilation system. Operators can, therefore, identify and shut down their systems, to isolate acute leaks effectively. The possibility of losing large quantities of tritium may justify the need for an inert gas secondary containment. This is the case for Darlington TRF and the AECL tritium laboratory at Chalk River.

Several companies discussed the chronic loss of tritium through the walls of uranium getter beds. The information on hydrogen and tritium diffusion through stainless steel is documented, and calculations can be done to estimate what the release may be. There was, however, no empirical information available from any facility reviewed for this report.

The staff at the Tritium Laboratory at Chalk River believes that the diffusion of tritium from the getter bed contributes a significant amount to the tritium concentration in the secondary containment glove box. The size of this contribution is, however, not quantified.

The operational approach to reducing this chronic loss is to minimize the duration and temperature of the heating process to release the required amount of tritium gas.

5.6 Loss Due to Pipeline Purging

Some facilities purged or released sections of pipe work directly to the fume hood ventilation system. This is not "good practice". It is possible to design tritium handling rigs to remove all the tritium from vessels and pipe work by reabsorbing onto getter beds. This can be done with or without additional inert gas purging.

Where it is not possible to recover tritium from pipe sections, these should be designed to be as small as possible. Work has been done in this area by the GTLS manufacturers in Canada and overseas.

5.7 Abatement

In discussions with the engineers from the companies mentioned in this report, there was full agreement that the best place for any abatement technology was as close as possible to the source of the leak or release. It should be noted in the discussion on ventilation, section 5.8, that there is no abatement on any stack releases.

There are several examples of tritium abatement systems in use at the facilities reviewed in this report. All the inert gas glove boxes contained a gas adsorption system, using recirculation pumps and getter beds. Some pipe and valve inert gas purging systems also use a getter bed to remove the tritium.

A good example of an abatement system to reduce chronic releases is the vacuum exhaust oxidation and molecular sieve adsorption system at Mb Microtec. Similarly, there are oxidation and water vapor condensation systems on the Darlington TRF and the GE Healthcare facility. Both of these facilities have the advantage of being able to recycle condensed water back into the process.

5.8 Ventilation

The ventilation system in tritium handling facilities is intended to protect the workforce from transient releases of tritium into the working area. There are different recommended air change rates in different countries. Those facilities that had specific information on the air change rate quoted figures between 5 and 15 air changes per hour. North American codes and guidelines for radiochemical laboratories recommend 8 to 10 air changes per hour, with a minimum of 6. An appropriate minimum standard for tritium facilities would, therefore, be six air changes per hour.

The larger nuclear facilities had ventilation systems that collected air from a number of areas and discharged the air to the environment through a vertical stack. None of the facilities reviewed in this report had any tritium abatement equipment on the stack discharge.

5.9 Release Point Design

The aerial release point for all the tritium facilities reviewed in this report was a vertical stack. Their heights varied from 70 m down to 9 m. At a tritium facility, the effectiveness of a stack in dispersing the released air can be determined by measuring the tritium gas and water vapor in the air. Those facilities with stacks above 40 m high, with the point of discharge clear above the roof line, had very low measurements for tritium in air and rain water. A considerable amount of stack design information is available from organizations like the American Society of Heating, Refrigeration and Air-conditioning Engineers (ASHRAE), the American Conference of Government Industrial Hygienists (ACGIH), and the US Environmental Protection Agency (EPA). These organizations emphasize the importance of having stacks sufficiently high to avoid releasing waste gases into the recirculation zones around buildings.

Both the Canada Labour Code and the Ontario Ministry of Labour recommend using ASHRAE and ACGIH standards and guides for occupational health and safety in industrial facilities.

It is unlikely that some of the smaller stacks reviewed in this report would meet the height design guidance from these organizations.

5.10 Tritium Recovery

Two operational tritium recovery facilities were reviewed in this report, namely the Darlington TRF and the NTP Radioisotopes Facility. The GE HealthCare facility is not yet operational, as it is still being commissioned.

The Tritium Removal Facility at Darlington demonstrates the practicality of handling a very large quantity of tritium-contaminated material and extracting a small mass quantity of tritium gas. The removal of tritium from out-of-date GTLSs at the NTP facility is so successful that they no longer purchase tritium gas to manufacture new light sources. The contrast in engineering between these facilities is dramatic – one being a very large and complex controlled facility, the other being a very small and simple process. What is common to both of them is that they are designed and engineered for a well-characterized feed material.

5.11 Tritium Storage

Within Canada, tritium is adsorbed onto titanium metal getter beds for long-term storage. This is done at the Darlington TRF. Uranium metal powder is widely used for getter beds in the tritium industry. There are also other metal alloys available for specific applications. The current practice of using uranium getter beds was never questioned, at any time during this review, whether in Canada or overseas. The use of uranium beds for the storage of tritium in production facilities can be considered best practice.

5.12 Performance Metrics

Best practice should be encouraged within the Canadian tritium handling industry. However, in order to determine what is best practice, there is a need to have quantifiable measurements. Historically, the radiation dose to the workforce and to the public was the determining parameter for acceptable performance. On its own, this has been a successful practice, but this approach has given rise to environmental contamination issues and non-compliance with the NSCA and associated Regulations. Also, it has not encouraged the industry to continuously improve its operating performance. One reason for this discrepancy is the way in which the dose to the public is calculated. Each critical group around a facility is unique, and therefore it is not really appropriate to compare the calculated public dose at one site with another.

A more appropriate metric for measuring the performance of a tritium handling facility would be one that allows direct comparison from one user to another.

In producing this report, several sets of data from individual facilities and individual processes have been reviewed. It has been possible to calculate losses to the environment of tritium for individual unit processes and overall operational performance. The following is a summary of the losses reported, losses calculated or estimated, as found in the text of this report:

- transferring tritium from getter bed to getter bed: loss 0.01%
- complex tritium removal processes: loss 0.03%
- production of gaseous tritium light sources: loss 0.4%

In Canada, it would be possible to establish a performance metric that requires licensees to report the percentage of losses to the environment and transfers to any waste facility. For new facilities, these performance metrics could be used as design parameters. It should be noted that licensees keep inventory records for tritium, as part of the internal management processes, and make some of this information available in their annual compliance reports.

Having a metric that measures another aspect of performance may help to encourage continuous improvement to reduce tritium losses within the industry.

5.13 Tritium Releases to Sewers

In all the facilities visited during this study, there was very little direct release of tritiated water to sewers or surface waters. The primary source of tritiated water to sewers was from decontamination of surfaces and general janitorial cleaning of surfaces and laundry.

GE Healthcare historically made large liquid releases to surface water and sewers. This practice has ceased, following regulatory pressure, and liquid wastes were stored on-site pending the construction of the tritium separation facility.

6 CONCLUSIONS

This review of tritium handling facilities has generally shown that Canadian practices are comparable with what is done at overseas facilities. Some specific practices, if adopted, could further reduce the releases of tritium to the environment. The following is a good practice list, as identified from the review:

1. High performance vacuum equipment should be used for gaseous tritium handling facilities.

2. High-quality primary containment is the most important control feature for handling tritium.

3. Uranium getter beds for operational storage of tritium gas are widely used, and considered good practice.

4. Titanium getter beds are considered good practice for the long-term storage of tritium gas.

5. Intentional release of tritium gas from pipe work and vessels is not good practice. Direct adsorption onto getter beds or inert gas purging and capture onto getter beds would be good practice.

6. The use of oil-free scroll pumps facilitates the use of subsequent technology on the exhaust. There is some limited evidence that they may reduce the concentration of HTO being released in the exhaust.

7. The removal of tritium gas and HTO from vacuum pump exhaust should be considered good practice, provided there is a treatment or disposal route for the abated tritium.

8. Secondary containment of getter beds can reduce chronic releases, particularly for beds that are used at elevated temperatures over prolonged periods of time.

9. The most effective use of abatement technology occurs at the point of generation of the release.

10. Ventilation systems should have appropriately designed release points (stacks) to achieve good dispersion of tritium gas and tritiated water vapour.

7 GLOSSARY

For the sake of simplicity, some terms are defined in plain language and may differ from definitions in standard references.

abatement process	Processes intended to reduce, minimize or eliminate a contaminant substance from a release point.
adsorb	The process where a substance adheres onto the surface of a material. By applying some effort or energy, the substance can often be released from the surface. This is called desorb. When gases adsorb on to the internal surfaces of pipes, this process of desorption is often referred to as "de-gas".
ALARA	Principle for radiation protection, according to which exposures are kept *as low as reasonably achievable* below regulatory limits, with social and economic factors being taken into account.
Amersham bed	Tritium is often transported in Canada and around the world in a tritium storage bed, designated as the Amersham AY 0666. It is often referred to as the Amersham transport container or an Amersham bed. It is a stainless steel cylinder about the size of a large coffee mug. When fully loaded it contains up to 1.85×10^{15} Bq.
Becquerel	Unit of activity, the rate at which transformations occur in a radioactive substance. 1 Becquerel (Bq) = 1 transformation or disintegration per second.
bellows valves	A type of gas flow control valve often used in vacuum systems or when handling hazardous gases. The bellows section of the valve is sealed to the valve body and to the valve operating lever or stem. This creates a secondary containment, to prevent loss of vacuum or hazardous gases.
bubbler	When air containing tritiated water vapour is bubbled through normal water, the tritiated water collects in the bubbler. This process is used to sample air for tritiated water. Often, two or three bubblers are connected in series, to ensure good sample collection. Tritium gas can be sampled using bubblers if it is first converted to tritiated water using heat or a catalyst.

cascade ventilation system	A facility ventilation system can be designed to flow from areas of no contamination to areas of increasing contamination (or risk of increasing contamination). This means that any release of a hazardous substance in an area will tend to be swept towards areas of high or potentially higher contamination. This type of ventilation is often called a cascade ventilation system (see also plenum system).
Class 1B licence	After power reactors, the next highest level of nuclear licenses granted under the *Nuclear Safety and Control Act*. Tritium processing facilities that use more that 10^{15} Bq per year are in this licence category.
fume hood	A ventilated enclosure, into which equipment can be placed and, if required, operated by hand. It is not sealed, but has limited openings through which air is continuously drawn in, thus limiting any hazardous material from coming out into the room where the fume hood is located.
getter bed	A metal or metal alloy that adsorbs gases and often reacts with them to form solid compounds. They are used to remove trace of unwanted gases from systems, and are often similar in design to the tritium storage beds (see below).
glove box	This is a sealed box with windows, for situations where hazardous material are being used. Rubber gloves are attached to the interior walls of the box, to allow a person standing outside the box to work inside the box. The gases inside of the box can be controlled; air can be removed and replaced with another gas, if required.
hydrogen isotopes	Nuclides of an element that have the same number of protons, but different numbers of neutrons, are called *isotopes* of that element. Hydrogen has three isotopes: Hydrogen-1 (common hydrogen, with a nucleus of only one proton), Hydrogen-2, also called deuterium (one proton and one neutron), and Hydrogen-3, also called tritium (one proton and two neutrons).
liquid scintillation counting	Tritium is a very weak beta radiation emitter. It is usually measured by mixing a sample with chemicals that emit light when they come into contact with beta radiation. The tritium sample and the light emitting chemical mixture are placed inside a light measuring instrument, called a scintillation detector. This is calibrated to count the amount of tritium in the sample.

molecular sieves	Some materials are very good at removing contaminants from the air. They act like a chemical filter that can be made to remove specific compounds from a gas stream. In this case, water vapour is selectively removed.
membrane valve	A type of valve used in vacuum systems, which relies on a polymer membrane to achieve a seal.
Plenum (system)	In a cascade ventilation system it is necessary to control the flow of incoming air. This is done using separate ventilation ducts with appropriate fans and baffles as necessary. If this is not done, areas or rooms could have too much air or not enough. Doors may not close or could not be opened. The flow of contaminated air could be reversed.
reactor moderator	An essential part of a nuclear reactor, used to slow down or "moderate" neutrons produced by the nuclear fuel. In the CANDU reactor system, this is a type of water referred to as heavy water. Heavy water is composed of deuterium.
release point	The place where waste material is released from a process and into the environment. This could be the exit from a chimney, a flue or a stack. For liquids, it could be a pipe to a river, lake or the sea.
SAFARI	A 20 MW research reactor in South Africa.
stack	A release point for gas, air or fine particles, which allows the waste stream to mix with the surrounding air, in order to dilute and disperse the waste material. A stack is usually much higher than any surrounding buildings and points vertically upwards.
tritiated water	Normal water is made up of two atoms of hydrogen and one atom of oxygen, and is given the chemical formula H_2O. If one or both of the hydrogen atoms are replaced with tritium atoms, the water is called tritiated water, and will have the chemical formula of either HTO or T_2O.
tritium	A radioactive form of hydrogen, which is produced both naturally and by human activities. The ionizing radiation from tritium is a beta particle. Tritium is produced during normal operation of Canadian nuclear reactors.

tritium storage bed	Some metals have the ability to adsorb hydrogen gas and tritium gas onto their surface and form solid compounds (called *hydrides* for hydrogen or *tritides* for tritium.) When heated, these compounds release the hydrogen or tritium gas. These metals therefore represent convenient storage materials for hydrogen and tritium gases. For tritium gas storage, finely divided metals are used in stainless steel containers. The size of these storage beds varies from as the size of an egg cup to as large as a 2-foot length of drain pipe. Tritium storage beds are referred to by various operators as "getter beds", "pyros", "pyrophoric uranium beds", and "adsorber" beds. The most commonly used metals for the storage of tritium gas are uranium, titanium, palladium and alloys of vanadium and iron.
turbo molecular pumps	When an extremely low vacuum is required, additional pumps are needed to take over where the standard vacuum pumps reach their limits. The turbo molecular pump is an example of one of these. It works by imparting momentum to molecules of gas left in the vacuum.
vacuum pumps	There are two types of vacuum pumps commonly used in the tritium processing industry: the oil-filled vane pump and the dry scroll pump. The oil-filled vane pump has been in use in the vacuum industry for over a hundred years. It is reliable and easily maintained. However, the oil comes into contact with the tritium and becomes heavily contaminated. This poses a hazard during maintenance, and the disposal of contaminated oil is becoming more difficult. The dry scroll pump has a similar performance to the oil-filled pumps without the problem of contaminated oil handling and disposal.

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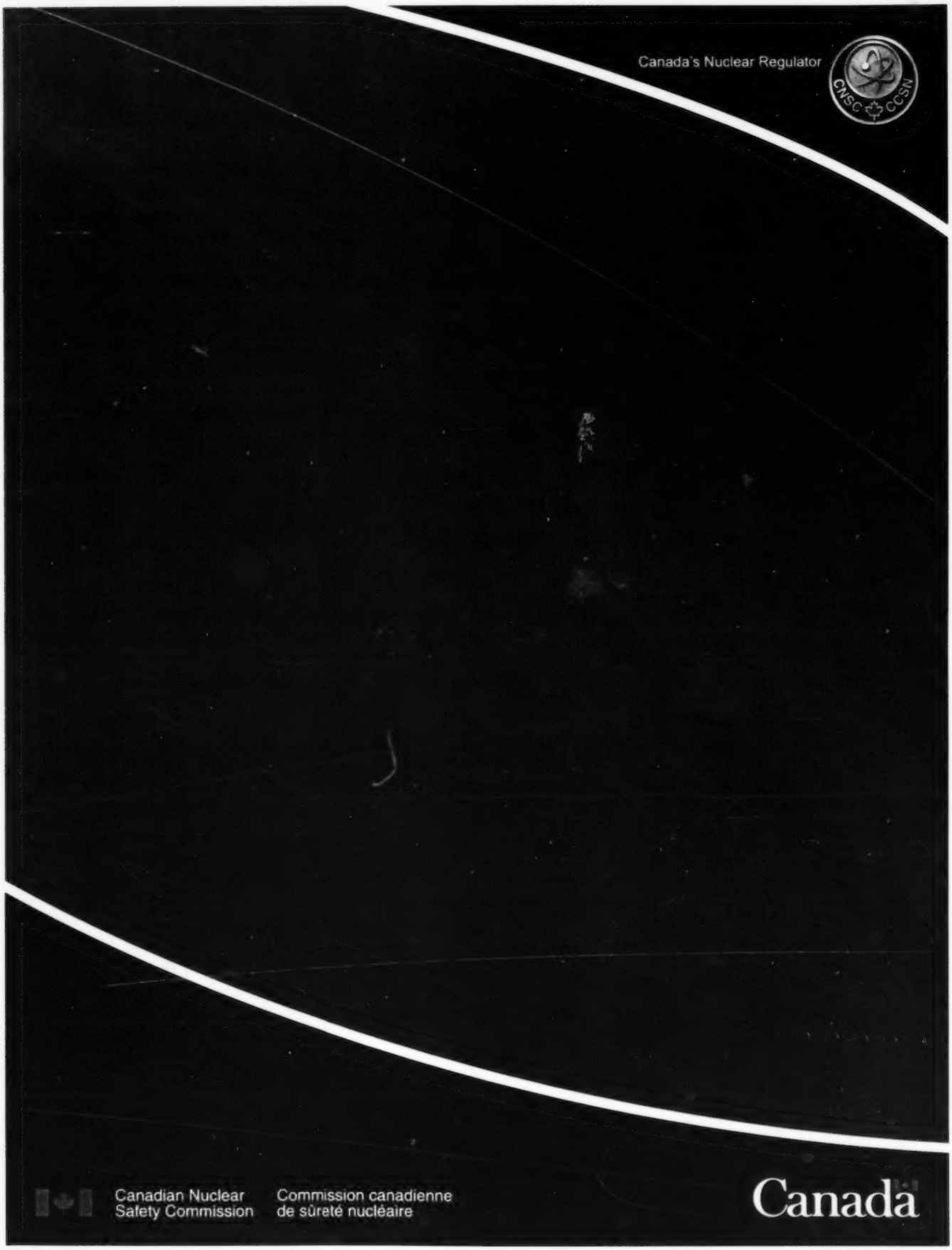
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